BULLETIN 53

Geology of Questa Quadrangle, Taos County, New Mexico

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Geology and ore deposits of the southwestern quarter of the Taos Range of the Sangre de Cristo Mountains and the Taos Plain to the west

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Introduction

This report describes the geology and mineral deposits of the southwestern quarter of the Taos Range of the Sangre de Cristo Mountains, a fault-block range with complex geology, and the Taos Plain, a bolson, to the west.

The study was made by the New Mexico Bureau of Mines and Mineral Resources in cooperation with the U. S. Geological Survey as part of a study of the entire Taos Range. Field work began in the summer of 1947 and continued during the summers through 1950. Work done in the northern half of the area has been reported in "Geology of Costilla and Latir Peak quadrangles, Taos County, New Mexico," issued as Bulletin 42 of the State Bureau of Mines and Mineral Resources.

LOCATION AND ACCESSIBILITY

Questa quadrangle is in the north-central part of Taos County, between latitudes 86°30' and 36°45' and longitudes 105°30' and 105°45'. The region is served by State Highway 3, which runs north from Taos through Questa to Colorado. State Highway 38 extends east from Questa to Red River; State Highway 111, a graded road, extends west from near Arroyo Hondo on Highway 38 to Tres Piedras. Other roads extend up Rio Hondo and Cabresto Canyons. The principal towns are Questa (population 250), Arroyo Seco (population 600), and Arroyo Hondo (population 700).

PREVIOUS WORK

Previous geologic work within the quadrangle has been confined to reconnaissance mapping and detailed study of the Questa molybdenum mine. A geologic map, scale 1:253,000, including this quadrangle, was compiled by Stevenson (1881) as part of the Wheeler survey. Bryan (1930, p. 116-118) described the basalts and gravels west of the mountain front. Gruner (1920) described the geology of the southeastern corner of the quadrangle.

The Questa molybdenum mine was described initially in a brief paper by Larsen and Ross (1920). More detailed studies have been made by Vanderwilt (1938) and Schilling (1956).

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Geography

SURFACE FEATURES

Maximum relief within Questa quadrangle is about 5,600 feet, with the lowest point, 6,500 feet, on the Rio Grande at the southern border, and the highest point, 12,106-foot Lobo Peak. The area can be divided into two physiographic subdivisions: (1) the Taos Range of the Sangre de Cristo Mountains, and (2) the Taos Plain.

The Taos Plain covers the western half of the quadrangle. Elevations range from 7,000 feet at the rim of the Rio Grande gorge to 8,000 feet along the mountain front to the east. The Rio Grande gorge extends southward across the plain and ranges in depth from 300 feet at the northern edge of Questa quadrangle to 500 feet at the southern edge.

The Taos Range of the Sangre de Cristo Mountains covers the eastern half of the quadrangle. The prominent features are the steep western front, high peaks and glaciated valleys, and the Red River and Rio Hondo drainages.

CLIMATE

The region is semiarid, although the range in altitude produces large variations in temperature and precipitation. The annual precipitation varies from less than 8 to more than 20 inches. Temperatures in winter range from -25° to 50°F, those in summer from 30°F to 90°F. The higher precipitation and lower average temperatures occur in the mountainous areas. From May to October, the moisture falls as rain or hail, except on the high peaks, where snowstorms may occur throughout the year.

Geology

SEQUENCE OF ROCKS

INTRODUCTION

The Taos Plain has a geologic setting very different from that of the Taos Range of the Sangre de Cristo Mountains. In the Taos Range, Precambrian metamorphic rocks (amphibolites, schists, and quartzites) and granite crop out over two-thirds of the area within Questa quadrangle. Tertiary volcanics (andesite, latite, and rhyolite) and granite stocks crop out over much of the remaining area. Dikes of rhyolite, monzonite porphyry, latite, and andesite are common. Scattered outcrops of Permo-Pennsylvanian sediments occur along the northeastern edge of the quadrangle.

In contrast, the Taos Plain is covered by a series of late Quaternary-Tertiary basalts and interbedded gravels. East of the Rio Grande, recent fan gravels cover the basalts.

PRECAMBRIAN ROCKS

Undifferentiated Metamorphic Rocks (p€m)

The oldest rocks in Questa quadrangle are amphibolites and hornblende schists, interlaid quartzites and quartz-mica schists, and layers of massive quartzite. The amphibolites, schists, and small lenses of quartzite make up the undifferentiated metamorphic rocks (p€m) shown on the map (pl. 1). Where possible, the quartzite exposures have been mapped as a separate unit (p€q). These metamorphic rocks crop out over large areas throughout the part of the Taos Range covered by this report and are similar to rocks of the Valdito formation of the Picuris Range to the south (Montgomery, 1953).

Amphibolite and hornblende schist. These rocks are interlayered with other metamorphic rocks throughout the Taos Range in Questa quadrangle.

The amphibolite and hornblende schists are massive to well-foliated rocks that range from black to dark green. Both have similar mineral content. Hornblende, andesine(?), and quartz in decreasing amounts are the important minerals. Apatite, sphene, and magnetite occur more sparingly. Epidote is abundant along fractures and quartz veins cutting the amphibolite and schist. Hornblende commonly is altered to chlorite; the feldspars to sericite. The amphibolite lacks foliation and is low in quartz; the hornblende schist is foliated and contains a higher percentage of quartz.

The amphibolite and schist may have been derived from basic volcanic rocks, but conclusive evidence is lacking.

Quartz-mica schist and gneiss. Quartz-mica schist and gneiss which are interlayered with the amphibolite and hornblende schist are well exposed north of Cabresto Creek in the northeast corner of Questa quadrangle.

Biotite up to 2 mm in diameter makes up approximately 45 percent of the rock. Small crystals of feldspar (40%) and quartz (15%) are intergrown with the biotite. Varying amounts of muscovite, almandite garnet, epidote, chlorite, and calcite may be present.

The quartz-mica schist and gneiss may have been derived from shale, sandstone, or rhyolite; again, however, conclusive evidence is lacking.

Cabresto Metaquartzite (p€q)

The Cabresto metaquartzite was named (McKinlay, 1956) for exposures along lower Cabresto Creek, where the formation crops out on both sides of Cabresto Canyon for over 5 miles. The formation is best exposed along the north side of the canyon, 4 miles east of Questa. Quartzite tentatively assigned to the Cabresto metaquartzite forms a narrow band extending east from the mountain front north of San Cristobal Creek to Lobo Peak. Several smaller areas are found along the mountain front to the south. Quartzite exposed in the Taos Range east of Questa quadrangle has been called Pueblo quartzite by Gruner (1920).

Maximum thickness in Questa quadrangle is about 400 feet. Thin layers of quartzite in the amphibolite, hornblende schist, and quartz-mica schist and gneiss, where they could not be mapped separately, have been included with the undifferentiated metamorphic rocks.

The quartzite is a cream to gray, or reddish-brown, coarsely crystalline rock. Along Cabresto Canyon it is made up of massive, 2- to 10-foot layers separated by thin muscovite or biotite-magnetite-garnet bands. Within the massive quartzite, alined magnetite grains occur in layers 2 inches to 1 foot apart, and parallel the mica layers.

When examined microscopically, the massive quartzite is a mosaic of quartz grains which commonly show wavy extinction. Original grain boundaries and cement are destroyed. Scattered flakes of muscovite and sillimanite bunches occur along microscopic shear planes.

Layers of graphite-mica gneiss and sillimanite-biotite gneiss locally are interlayered with the massive quartzite, and have been mapped as part of this unit.

Graphite-mica gneiss. Graphite-mica gneiss is exposed in a few places along Cabresto Creek. Under the microscope it is an intimate intergrowth of equigranular orthoclase and quartz crystals enclosing alined graphite flakes. The graphite content varies from 1 to 10 percent. Muscovite and sphene occur sparingly. This rock may have been formed by the metamorphism of carbonaceous shale.

Sillimanite-biotite gneiss. Sillimanite-biotite gneiss is also found along Cabresto Creek as layers ranging from 1 foot to about 50 feet in thickness. The rock is commonly granitic in appearance and exhibits a persistent foliation. Principal minerals observed microscopically are biotite, quartz, feldspar, sillimanite, and muscovite. The sillimanite occurs in swirling bunches along the foliation planes, and in places appears to replace muscovite.

The exact relationship between the Cabresto metaquartzite and the undifferentiated metamorphic rocks is not clear cut. Along Cabresto Creek the quartzite is overlain by the undifferentiated metamorphic rocks. In the San Cristobal Creek area the quartzite appears to be interlayered with hornblende schist, suggesting that the quartzite may be a unit in the undifferentiated metamorphic rocks. The Cabresto quartzite is overlain unconformably by silicified conglomerate fPPsc(?) of possibly late Paleozoic age.

Granite and Granite Gneiss (p€gr)

Cream to pinkish Precambrian granite and granite gneiss outcrop over larger areas throughout the Taos Range.

The texture of the granite varies from a fine-grained aplite to pegmatitic material. Foliation may be well developed or entirely absent. The most characteristic phase is a medium-grained, slightly foliated rock.

In general the granite is composed of pinkish microcline, glassy quartz, white albite, greenish-brown biotite, muscovite, apatite, sphene, and magnetite. The relative proportions of these minerals vary from place to place. For example, biotite which is common in the more gneissic phase is often absent in the pegmatitic material. The biotite is often altered in varying degrees to chlorite. The feldspars occur as rounded, irregularly sized grains with good cleavage planes. Grain size of the feldspars ranges from about 3 mm in diameter in the medium-grained rock to 1-2 inches in diameter for the pegmatitic phase.

Specimens examined under the microscope show granulation and partial recrystallization of the mineral constituents. The biotite is commonly alined along small shear planes. Much of the albite is turbid and corroded, with the development of small muscovite flakes in and around the crystals. In contrast, the microcline is usually clear and not corroded. Apatite is the only mineral that consistently shows crystal faces. The secondary minerals epidote and chlorite occur in varying amounts along shear planes and fracture zones. The approximate mineral composition of the medium-grained granite is 35 percent microcline, 20 percent albite, 35 percent quartz, 5 percent biotite, 3 percent muscovite, 2 percent apatite, sphene, and magnetite.

Areas of mixed rock or migmatites were formed in the metamorphic rocks adjacent to the granite. In general, near the granite the rocks of the undifferentiated metamorphic unit are coarser, contain more feldspar, and have lost all traces of primary textures and structures.

Granite lenses and layers in the migmatites from southeast of San Cristobal to the Rio Lucero differ somewhat from the Precambrian granite in the main granite bodies. Where this granite is exposed along the lower Rio Hondo it is gray and composed of orthoclase and quartz. As no larger bodies of the gray granite are known to occur, this granite may represent an early phase of the more predominant type of Precambrian granite.

The Precambrian granite intrudes the Cabresto metaquartzite and the undifferentiated metamorphic rocks. The Tertiary volcanics lie unconformably on the granite.

Pegmatites (p€p)

A few scattered pegmatite dikes occur in the Taos Range portion of the quadrangle, more commonly along the margins of Precambrian granite bodies. Most of the dikes are small and in general are composed of orthoclase and quartz with a few 1- to 3-inch books of muscovite. Magnetite and some ilmenite occur along the margins of pegmatites along the Rio Hondo. Milk-white quartz veins, which are common in the undifferentiated metamorphic rocks, are closely associated with these pegmatites.

The pegmatite dikes intruded the Precambrian granite and undifferentiated metamorphic rocks, but not the post-Precambrian rocks.

PALEOZOIC ROCKS

Sangre de Cristo(?) Formation (PPPsc)

Well-silicified outcrops of interbedded conglomerate, sandstone, shale, and limestone are exposed north of the mouth of Columbine Creek between the Red River and Cabresto Creek, as well as north of Cabresto Creek.

The largest exposures are along a 400-foot zone extending southeast from Cabresto Creek to north of the Questa molybdenum mine. Here the sedimentary rocks lie unconformably on Cabresto metaquartzite and dip 60-70 degrees to the southwest. Tertiary volcanic rocks overlap the sedimentary rocks to the southwest. On the ridge north of the Questa molybdenum mine, a soda granite stock intruded and cut off the belt of sediments.

To the south of this stock a continuation of the belt of sedimentary rocks extends southwest to above the large dump of the Questa mine. Here the sedimentary beds are badly broken and tilted; attitudes recorded ranged from N. 30° W. at 45° E. to N. 30° E. at 55° W. These sediments overlie Precambrian granite, metaquartzite, and the undifferentiated metamorphic rocks, and are overlain by Tertiary volcanic rocks.

TABLE 1. SECTION OF SANGRE DE CRISTO(?) FORMATION ON CABRESTO CREEK

DESCRIPTION	THICKNESS (feet)
Volcanic rocks	
Sangre de Cristo(?) formation	
Conglomerate (mainly quartzite, some schist and gneiss)	35
Conglomerate and shale layers (1-3 ft thick)	25
Shale, gray and siliceous	200
Fine-grained sandstone, reddish and arkosic	60
Basal conglomerate (quartzite boulders as much as 3 ft in diameter)	50
Total thickness	370
Cabresto metaquartzite	

Schilling (1956) has mapped the downward extension of these sediments where they are exposed in the Questa molybdenum mine.

A third exposure is north of the Red River, a short distance west of the mouth of Columbine Creek above the old road and just north and above the present road. Here red siltstone and conglomerate with thin layers of sandstone strike N. 25° W. and dip 70° W. The beds are exposed for approximately 300 feet along the road. On the north Tertiary andesitic volcanics overlie the sedimentary rocks.

No fossils were found. However, these sedimentary rocks are tentatively assigned to the Permo-Pennsylvanian Sangre de Cristo formation on the basis of their lithology and structural relationships with other rock units.

TERTIARY ROCKS

Andesite Flows and Pyroclastics (Ta)

Andesite flows, breccias, and tuffs are exposed along the Red River and Cabresto Creek. These exposures extend north of Cabresto Creek into Costilla and Latir Peak quadrangles (McKinlay, 1956). South of Red River, andesite is absent except along the mountain front between San Cristobal and Lobo Creeks.

The andesite ranges up to 2,000 feet in thickness within the quadrangle.

The andesite-flow material is in general a fine-grained purplish or gray rock. Certain flows are porphyritic, with phenocrysts of andesine and hornblende or augite and an aphanitic groundmass that is usually glassy and contains disseminated hematite. The breccias consist of angular fragments of andesite flow, from 1 inch to 1 foot in diameter, in fine-grained purple to green matrix. The tuffs are purple, green, and gray and consist of fragments of andesite embedded in a fine-grained ash matrix.

As the volcanic rocks extend southward from Costilla and Latir Peak quadrangles, it becomes increasingly difficult to separate the andesite from the overlying Latir Peak latite; in some areas it was necessary to map these two units together. However, in such cases the andesite probably predominates and the latite may actually be absent in a given area.

The age determination and correlation of the andesitic rocks are difficult, even in areas of good exposures. The andesite complex lies unconformably on the Precambrian and later Paleozoic rocks. It is overlain by Latir Peak latite, or where the latite is absent, by rhyolite. However, the lower part of the latite may intertongue with the andesite. Dikes of granite, monzonite porphyry, and lathe cut the andesite. On the basis of present knowledge, the andesite can not be dated any closer than early to mid-Tertiary.

Latir Peak Lathe (Tlp and Tlpi)

The Latir Peak latite was named (McKinlay, 1956) for Latir Peak, in Latir Peak quadrangle to the north, where the rock is well exposed. The latite covers larger areas in Latir Peak and Costilla quadrangles, but outcrops over a much smaller area in Questa quadrangle, thinning rapidly as it extends southward. Except for one area north of Cabresto Creek, no outcrop can be positively identified as Latir Peak latite, although areas of the earlier andesite may include latite.

The Latir Peak latite occurs as flows (Tip), sills(?), and dikes (Tlpi). It is porphyritic, with an aphanitic to glassy groundmass. The color of the rock in most of the outcrops is light gray, but near Latir Peak much of the rock is reddish. The texture and composition of the Latir Peak latite vary; specimens from some localities are andesitic in composition. The latite contains phenocrysts of plagioclase, quartz, biotite, and hornblende in a groundmass of feldspar and quartz. The plagioclase phenocrysts, which are between oligoclase and andesine in composition, make up about 35 percent of the rock. Biotite phenocrysts form approximately 5 percent of the rock. Hornblende forms about 2 percent of the rock. The groundmass is often glassy.

The age relations between the andesite and Latir Peak latite are confused. As a rule the andesite underlies the latite. However, latite layers occur in the upper part of the andesite, and andesite layers occur in the latite, suggesting that the upper part of the andesite unit intertongues with the Latir Peak latite. Some of the dikes mapped as Latir Peak latite (Tlpi) are andesitic in composition and may represent intrusive equivalents of the andesite volcanics.

Rhyolite volcanics overlie the Latir Peak latite, and rhyolite dikes cut the latite.

Granite (Tgr)

Stocks of Tertiary granite occur along the Rio Hondo and in the northeast corner of the quadrangle on both sides of Cabresto Creek.

The granite is a mottled pink to cream rock with pink orthoclase phenocrysts (as much as 10 mm), scattered phenocrysts of glassy quartz, white albite, and scattered biotite and/or hornblende. Under the microscope the texture is allotriomorphic with some granulation of crystal boundaries. The rock is made up of approximately 40 percent orthoclase, 35 percent quartz, 20 percent albite, 5 percent biotite, as much as 5 percent hornblende, and small amounts of magnetite, sphene, and apatite. The albite is altered along boundaries and fractures to sericite. Some chlorite has formed from the biotite. The rock textures indicate considerable cataclastic deformation. Quartz has been granulated and recrystallized along microscopic shears. The feldspars often have wavy granulated borders. Biotite is broken up and strung along shears. Probably the lack of subhedral crystals is due to the granulation.

The age relationships between this granite and the volcanics are obscured. The granite definitely intrudes the Precambrian rocks and late Paleozoic rocks. In Costilla quadrangle to the north, the granite appears to intrude the Latir Peak latite. In Questa quadrangle the granite and volcanics are in contact only in the northeast corner of the quadrangle, and no intrusive relationships were noted.

Rhyolite porphyry dikes cut this granite, but not the soda granite; molybdenite veins are associated with the soda granite stock, but not with this granite; the soda granite shows little granulation and definitely cuts the rhyolite volcanic rocks; and the soda granite never contains hornblende. All these facts suggest that this granite is older and is distinct from the soda granite, although both are similar mineralogically.

Rhyolite Tuffs and Flows (Tr)

Gray to light-pink rhyolite tuffs and aphanitic flows are exposed along the high ridge north of the Red River. This rhyolite is found throughout the Taos Range (McKinlay, 1956).

The rhyolite ranges from 10 to 450 feet in thickness. A gray welded tuff with dark streaks of glass and numerous small crystals of orthoclase and quartz is the lowermost unit. The flows above are gray to light pink, commonly with numerous small quartz and lesser feldspar phenocrysts.

Large areas of the rhyolite have been altered, so that correlation and dating are difficult. The rhyolite overlies the andesite and Latir Peak latite and is tentatively dated as mid- to late Tertiary in age.

Rhyolite Intrusives (Tri)

A swarm of rhyolite porphyry dikes extend north from the Rio Lucero to San Cristobal Creek, and dikes similar in texture and composition occur throughout the Taos Range. The individual dikes in the dike swarm trend northwest.

The rhyolite is a light-pink porphyritic rock with a fine-grained groundmass. Pink orthoclase and clear rounded quartz phenocrysts are a distinctive feature. Examined under the microscope the groundmass is usually completely crystalline and is made up of small intergrown crystals of quartz, orthoclase, and albite. Scattered biotite flakes are seen occasionally.

In the vicinity of the Questa molybdenum mine, rhyolite dikes cut the Tertiary andesite. The similarities of texture, composition, and structural relationships between the rhyolite dikes and Tertiary soda granite suggest that both may have been derived from the same parent magma and thus may be roughly equivalent in age. Some of the dikes may represent feeders for the rhyolite flows, although clear-cut relations are lacking.

Soda Granite (Tsg)

The soda granite crops out as two stocks along the Red River. These have been called (Schilling, 1956) the Flag Mountain stock (located along the mountain front at the Red River) and the Sulphur Gulch stock (located at the east edge of the quadrangle and north of the Red River). A small body of soda granite crops out just north of the Red River opposite the mouth of Columbine Creek. Another granite mass south of the Rio Hondo was mapped as part of this rock type. Dikes of soda granite are found around the stocks.

This granite has been described by Larsen and Ross (1930), Vanderwilt (1938), and Schilling (1956). Because of the low mafic mineral content Larsen and Ross called this unit alaskite porphyry. Vanderwilt decided that the alaskite is only a local phase, and has termed the rock an albite granite. Schilling concurs with Vanderwilt, but uses the term soda granite.

The soda granite is a fresh-appearing pink, porphyritic to inequigranular rock. When porphyritic it shows scattered rounded quartz and orthoclase phenocrysts. The quartz phenocrysts are generally rounded and corroded, and range in size from 2 mm to 6 mm. The pink orthoclase phenocrysts are generally euhedral in shape and extend to as much as 2 cm in size. The groundmass is predominantly quartz, orthoclase, and albite, with minor biotite and magnetite. The average grain size of the groundmass is in general less than 1 mm. The composition of this granite varies slightly from exposure to exposure.

The soda granite intrudes the Tertiary volcanic rocks, including the youngest unit, the rhyolite flows and pyroclastics. Although the soda granite is quite similar mineralogically to the earlier Tertiary granite, certain differences suggest that the soda granite is younger. Mineralogically the soda granite has more albite and no hornblende. Rhyolite porphyry dikes cut the earlier Tertiary granite, but not the soda granite;

the soda granite is fresher appearing, less granulated; and molybdenite deposits are associated with the soda granite bodies, but not with the earlier granite. The soda granite is tentatively dated as late Tertiary in age.

The similarities in age and mineralogy of the rhyolite volcanics, rhyolite porphyry dikes, soda granite, and other Tertiary granite suggest a common parent magma, although evidence is not conclusive.

Monzonite Porphyry Dikes (Tmp)

Long thin monzonite porphyry and quartz monzonite dikes are scattered throughout the Taos Range.

The monzonite porphyry ranges from light greenish gray to gray. Textures and mineral compositions vary from place to place. The principal minerals are orthoclase, albite, quartz, biotite, and hornblende. The orthoclase forms white to pinkish phenocrysts that are in places 2 inches in diameter. White albite phenocrysts as large as one-half of an inch are common. Rounded quartz phenocrysts range to as much as three-quarters of an inch in diameter. Crystals in the groundmass are generally not over one-eighth inch in size and consist of quartz, feldspar, and scattered biotite and hornblende.

The monzonite dikes are one of the youngest dike rocks in the area, and cut the Tertiary volcanic flows and pyroclastics. Dikes assigned to this unit are exposed in the Questa molybdenum mine workings, where they cut the soda granite stock (Schilling, 1956).

QUATERNARY-TERTIARY

ROCKS Basalts (QTb)

Light- to dark-gray basaltic to andesitic flows of olivine-rich rocks underlie the Taos Plain and are well exposed in the Rio Grande gorge. The flows range from 20 to 55 feet in thickness and extend under the alluvial fans along the front of the Taos Range. A low domal type mass of this rock forms Cerro Negro north of the community of Arroyo Hondo in the southern part of the quadrangle.

The flows are often vesicular, and are interlayered with beds of semi-consolidated sand and gravel. This basalt and basaltic andesite has been correlated by Atwood and Mather (1932) with the basalt of the Hinsdale formation of the San Juan region.

Accurate dating could not be made. This unit is tentatively dated as late Tertiary to Quaternary in age.

QUATERNARY ROCKS

Andesite (Qan)

A mass of gray porphyritic andesite forms Cerro Chiflo, an east-west trending ridge along the northern edge of the quadrangle on the Taos Plain.

The andesite is exposed in the Rio Grande gorge. Here the Quaternary-Tertiary basalt flows are in contact with the sides of the andesite mass which is exposed over the entire vertical extent of the western gorge wall. 'Whether the andesite intrudes the basalts or represents a hill of older andesite is not clear. Definite intrusive relations were not noted. This andesite is quite different from the Tertiary andesites in the Taos Range. To the west similar andesite is associated with the basalts. The uppermost basalt flow appears to butt against the andesite without being deformed by any intrusive action.

It is suggested that the andesite may be an extrusive dome, the andesite having been intruded up through the lower basalt flows and interbedded gravel as a dikelike mass, then spreading out on the surface as a dome, and later becoming partially buried by more flows and gravel. However, the possibility that the andesite is prebasalt or entirely intrusive cannot be ruled out until better evidence is available.

Coarse Fan Gravels (Qg)

Fan gravels lie west of the steep mountain front of the Taos Range. They dip westward at 5-20 degrees. The gravels are loosely consolidated and contain many thin sand lenses.

The coarse fan gravels are in places 3,000 feet thick. Basalt flows are interlayered with the gravels near the bottom of the gravel unit. In places basalt with only a thin veneer of gravel is encountered. The youngest fan gravels have been laid over the topmost basalt flows from Guadalupe Mountain.

Cemented Conglomerate

Angular conglomerate, with occasional lenses of sand, is exposed up to 200 feet above present streams and gulch bottoms in the areas of intense alteration along the Red River. Exposures were too isolated and small to be shown on Plate 1. Schilling (1956) called this unit "cemented conglomerate."

The angular conglomerate is made up of angular fragments of altered volcanic rocks washed from the large alteration areas and later cemented by limonite and hematite. This rock is so well cemented that in places it appears to be part of the older volcanic rocks.

This conglomerate now is a terrace deposit. The relatively small amount of downcutting since the formation of this unit suggests a late Pleistocene age.

Valley Alluvium (Qal)

The gravels and other unconsolidated materials on the present floors of the gulches, valleys, and cirques were mapped as valley alluvium.

Mud flows of debris from the alteration areas along the Red River have formed thick fans in Red River Canyon.

Although glacial deposits are widespread in the Taos Range east of Questa quadrangle, such deposits are less common within the quadrangle. Cirques at heads of tributaries to Columbine Creek contained small glaciers during Wisconsin time. Morainal deposits indicate that the glaciers did not extend much below 9,600 feet.

STRUCTURE

The most prominent structural features of Questa quadrangle are the block faulted Taos Range, bounded on the east by a thrust fault and on the west by normal faulting, and the downfaulted bolson which forms the Taos Plain.

Within the mountains a downfaulted zone bounded on the north by Cabresto Canyon and on the south by Red River Canyon extends eastward across the range (Schilling, 1956). Not only are the Tertiary volcanic and older rocks downfaulted in a complex pattern, but the alteration areas and most of the Tertiary soda granite stocks are localized within the zone.

FOLDS

Folding is not an important feature within the quadrangle. Precambrian rocks were folded along N. 70° E. and N. 20° W. axes. Some folding may have occurred in late Permian time, though the steep dips of the Sangre de Cristo(?) sediment could be due to tilting of Tertiary fault blocks. Tertiary and Quaternary rocks show no apparent folding.

FAULTS

Thrust Faults

The principal Laramide thrust fault along the east edge of the Taos Range is east of Questa quadrangle. Minor thrust faults in Precambrian rocks are indicated across upper San Cristobal Creek and north of Valdez, where a mass of quartzite lies above a crenulated zone of undifferentiated metamorphics.

Normal Faults

The Taos Range has been elevated and tilted eastward along a zone which approximately parallels the present position of the western mountain front. The evidence of a fault along the mountain front is based on apparent displacement of Tertiary volcanics and Precambrian quartzite, on faceted ridges, the steplike nature of the topography along the front, and the thick gravel deposits underlying the Taos Plain. The amount of vertical displacement is estimated to be more than 7,000 feet.

The latest displacement along this frontal fault zone is well developed east of the village of Costilla, in Costilla quadrangle to the north (McKinlay, 1956), where Quaternary basalt flows are broken.

The frontal fault zone trends south from the north border of the quadrangle to Lobo Creek. South of Lobo Creek the zone has a southeast trend. Normal faults and the rhyolite porphyry dike swarm in the mountains to the southeast of Lobo Creek have this same trend.

High-angle faults within the downfaulted zone along the Red River commonly have an east-west trend, although the fault pattern is irregular and is difficult to trace because of poor exposures and the intense alteration.

BRECCIATION

Areas of intense brecciation are common in the downfaulted zone along the Red River. These areas are not only brecciated but are intensely altered. The intensity of brecciation varies greatly; large masses of unbrecciated rock are surrounded by intensely brecciated rock.

Although the Tertiary volcanic and older rocks have been brecciated, the soda granite apparently has not been affected, a difference which suggests that the brecciation occurred during late Tertiary time.

FRACTURES

Fracturing is widespread in the mountains. Fracturing parallel to the normal faulting is common. Another group of fractures trend eastward, with steep dips to the north. Fracturing within the downfaulted zone is irregular and, where more closely spaced, is gradational with the less intense brecciation.

FOLIATION

Foliation in the Precambrian metamorphic rocks shows no predominant trend, although east-west trends with steep dips to the north or south are the most common.

METAMORPHISM

In general, the metamorphism of the Precambrian rocks is of low or medium grade. The metamorphic process which produced the mineral assemblages was, first, regional in nature and, second, was confined to local thermal effects near the Precambrian granite. The regional metamorphism granulated and recrystallized the Precambrian volcanic and sedimentary rocks into amphibolites, quartzites, and schists.

The intrusion of Precambrian granite into the older rocks locally raised the temperature, and higher grade metamorphic rocks were formed. Zones of migmatite were developed in the amphibolite by the soaking and lit-par-lit intrusion of granitic materials. The higher temperature and, possibly, introduction of water vapor from the granite magma produced areas of coarse quartz-mica gneiss within the quartzite. Muscovite flakes as large as one-half to three-quarters of an inch in diameter were formed near granite bodies. Also, sillimanite and locally tourmaline were formed in the mica schist and quartzites. Epidote is common in the amphibolite and hornblende schists. The epidote usually is confined to fractures and quartz veins but may be disseminated in local areas. The epidote is not common in the migmatite and is believed to be related to the pegmatite-quartz intrusive phase which followed the emplacement of the granite magma.

Mylonite zones were developed along faults in the older metamorphic rocks. Fine-grained muscovite-chlorite schist is the common rock in the mylonite zones.

ALTERATION

The brecciated rock in the downfaulted zone along the Red River has been intensely altered. These alteration areas are conspicuous because of their yellow color, "badland" topography, and treeless outcrops. Numerous gullies, steep slopes, and cliffs have been formed by the rapid erosion of the soft altered rock.

The Tertiary volcanics and older rocks all have been affected, the intensity of alteration apparently varying directly with the intensity of brecciation. In the alteration areas, the various rocks are leached and silicified. In places, a white, dense rock is formed, in which the original textures have been obliterated. Chlorite, pyrite, kaolinite, sericite, and quartz were the principal alteration minerals formed. Quartz veins are common. Weathering and oxidation of the pyrite has given the alteration areas their striking yellow, limonitic staining.

GEOLOGIC HISTORY

The history of the oldest rocks within the quadrangle began with the extensive deposition of basic volcanic rocks. Interbedded with the volcanic rocks were thick beds of quartz sand, siltstone, and clay. The thickness, extensive exposures, and purity of the presently exposed quartzite indicate that a large supply of quartz was available for long periods. The sand was free of impurities near the lower part and became increasingly more argillaceous as deposition continued. In places, organic shales were deposited. Deformation that preceded or accompanied the intrusion of the granite batholith obliterated most of the original textures and structures of the sedimentary rocks. The Precambrian rocks were deformed at least twice and were extensively eroded before the deposition of Paleozoic sedimentary rocks.

The history of the Paleozoic rocks is mostly hidden. Questa quadrangle is believed to have been a stable area throughout most of Paleozoic time. Uplift of part of the region in pre-Permian time is indicated by the conglomeratic nature of the Permian sediments. Thin beds of Mesozoic and Cretaceous rocks were probably deposited and later eroded.

During the Laramide revolution, the Precambrian rocks were thrust eastward over Paleozoic and Mesozoic rocks. Erosion during and after the Laramide deformation stripped the Mesozoic and Cretaceous rocks from above the Precambrian thrust block in the Questa area. A mature erosional surface probably was formed. In local areas, sand and gravel were deposited. During this period of erosion, the Precambrian rocks were weathered deeply.

At some time in the Tertiary, Eocene(?) or Miocene(?), andesitic and latitic pyroclastics and flows were deposited over most, if not all, of the area and were intruded by bodies and dikes of latite. Rhyolite tuffs were piled above the andesites and latites. Sand and gravel derived from a positive area of Precambrian rocks were interbedded in local areas with the rhyolite tuff and basalt.

Rhyolite dikes, monzonite porphyry dikes, and granite stocks were intruded near the close of the latite intrusive activity. Large blocks of the older volcanic rocks were uplifted, tilted, and in places badly fractured by the emplacement of the intrusive bodies.

The Sangre de Cristo Mountains were elevated in late Tertiary time in relation to the Taos Plain along an extensive zone of normal faulting parallel to the present mountain front. Normal faults also were developed in the mountains. Tertiary volcanics and older rocks were faulted down along the Red River.

The mountains were eroded during the Pleistocene by vigorous streams. The elevation of the mountainous areas continued, and in late Pleistocene the higher areas in the mountains were glaciated. During the Pleistocene, the Rio Grande depression was covered with thick flows of olivine basalt and basaltic andesite. These basalts were interbedded with numerous gravel lenses. As the basalts covered the gravels west of the mountains, wide valleys with gravel terraces and rounded ridges were being developed in the mountains to the east. At the close of the Pleistocene, additional block faulting displaced the basalts along the mountain front. The rejuvenated streams rapidly cut sharp V-shaped valleys into the more mature Pleistocene surface, and the basalts in the Rio Grande depression were covered with several hundred feet of alluvial fan gravels.

MINERAL DEPOSITS

Numerous prospects are scattered throughout the Taos Range in Questa quadrangle. Much of the prospecting in the Taos Range was centered around the town of Red River, east of the quadrangle, where numerous small gold pockets were found.

QUESTA MOLYBDENUM MINE

The molybdenite deposit of the Questa Molybdenum mine is the most important deposit within the quadrangle and is the only operating mine. Schilling (1956) has made a detailed study of this deposit. The Questa mine (also known as the Moly mine) is situated north of the Red River at the eastern edge of the quadrangle. The mine has been in almost continuous operation since 1920, when the Molybdenum Corporation of America, the present owners, acquired the property. Total production to January 1, 1956, was over 18 million pounds of molybdenite.

The molybdenite-bearing veins occur in a soda granite stock along a locally east-striking, south-dipping contact with Tertiary volcanic rocks. The veins are as much as 7 feet thick, and are largely quartz and molybdenite, with locally abundant biotite, fluorite, pyrite, chalcopyrite, calcite, and rhodochrosite.

Wall-rock alteration is not intense: Silicification is common, feldspar is altered to clay and sericite, and disseminated pyrite is scattered through the rock.

OTHER DEPOSITS

Many small mineral deposits have been prospected for molybdenum, gold, silver, copper, lead, zinc, and fluorite, particularly along the Red River. Apparently most of these deposits are Tertiary in age and commonly are associated with the Tertiary granite intrusive rocks. Veins are usually small and widely spaced.

The Precambrian graphite-mica gneiss has been prospected for graphite where the graphite is present in higher than normal concentrations. However, the concentration is too low for commercial exploration under present economic conditions.

The Precambrian pegmatite dikes examined showed no minable concentrations of valuable minerals. In Costilla quadrangle to the north, beryl, chrysoberyl, and scrap mica were found (McKinlay, 1956) in Precambrian pegmatite.

The mineralization within the quadrangle can be divided into three distinct types: (1) The Tertiary molybdenite-fluorite-pyrite-quartz vein mineralization which is associated generally with the alteration zones north of the Red River; (2) the Tertiary(?) chalcopyrite and galena minerals in small quartz veins, shears, and fractures within Precambrian rocks along the Rio Hondo; (3) the Precambrian pyrite zones within Precambrian quartzite and the undifferentiated metamorphic rocks along San Cristobal Creek.

At present it appears unlikely that additional ore deposits of economic worth will be found in Questa quadrangle. However, the area north of the Red River between Questa and the "Moly" mine is favorable for molybdenum mineralization. Most of the occurrences of molybdenite, fluorite, huebnerite, and chalcopyrite have been examined by means of pits and adits, but there has been little, if any, core drilling to test areas near some of the soda granite contacts. Until these contacts are tested adequately, the mineral values of the district cannot be assessed.

WATER

Practically all the available surface water from the mountains is committed, either for domestic use and local irrigation or for irrigation along the lower Rio Grande. The ground water of the Taos Plain probably is perched above the gently east-dipping basalt flows which are interbedded with the thick gravel deposits. The valleys of the Rio Hondo, San Cristobal Creek, and the Red River, and the level plains north of Questa and around Arroyo Seco are the only important areas of irrigation. There is little additional land suitable for irrigation within the quadrangle, even if water were available.

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